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NUTRIENTS IN THE POTOMAC RIVER BASIN

Norbert A. Jaworski, et al

Federal Water Pollution Control Administration
Annapolis, Maryland

May 1969

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Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Pollution Control Administration
U.S. Department of the Interior

Technical Report No. 9

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NUTRIENTS IN THE POTOMAC RIVER BASIN*

by

Norbert A. Jaworski
Orterio Villa, Jr.
Leo J. Hetling**

May 1969

* Presented at the Purdue Industrial Waste Conference, May 6, 7 and 8, 1969, LaFayette, Indiana

** Director, Research Unit, Division of Environmental Health Services, New York State Department of Health

45

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	iv
INTRODUCTION	1
DESCRIPTION OF THE POTOMAC RIVER BASIN	2
SAMPLING PROGRAMS	5
SOURCES OF NUTRIENTS (PHOSPHORUS AND NITROGEN)	7
1. Wastewater Effluents	7
2. Land Runoff	8
3. Total Basin Nutrient Loadings	12
TEMPORAL AND SPATIAL DISTRIBUTION OF NUTRIENTS IN THE UPPER POTOMAC BASIN	14
1. Phosphorus	14
2. Nitrite + Nitrate and Total Kjeldahl Nitrogen (TKN)	16
NUTRIENT AND CHLOROPHYLL CONCENTRATIONS IN THE ESTUARY	21
TEMPORAL DISTRIBUTION OF NUTRIENTS ENTERING THE POTOMAC ESTUARY	27
1. Temporal Variations	27
2. Mass Balances	30
NUTRIENT TRANSPORT	34
1. Transport Model for Phosphorus	34
2. Effects of Small Impoundments on Nutrient Transport	34
SUMMARY AND CONCLUSIONS	38
REFERENCES	40

LIST OF FIGURES

Number	Description	Page
	Major Municipal Wastewater Discharges, Potomac River Basin	4
2	Potomac Estuary	[illegible]
3	Nutrient Network, Potomac River Basin	
4	Land Use Comparison--Total Phosphorus PO_4, Potomac River Basin, 1966	[illegible]
5	Land Use Comparison--NO_2 + NO_3 as N, Potomac River Basin, 1966	11
6	Major Sub-basins, Potomac River Basin, Total Phosphorus (lbs/day).	14
	Major Sub-basins of Potomac River Basin— Inorganic Nitrogen (lbs/day).	17
8	TKN as N Isopleth (mg/l), Upper Potomac Estuary, May to October 1968.	[illegible]
9	NO_2 + NO_3 as N Isopleth (mg/l), Upper Potomac Estuary, May to October 1968	[illegible]
10	Total P as PO_4 Isopleth (mg/l), Upper Potomac Estuary, May to October 1968.	25
11	Chlorophyll Isopleth (μg/l), Upper Potomac Estuary, May to October 1968.	[illegible]
12	Nutrient Loadings and River Discharges, Potomac River, Great Falls, Maryland, 1966. .	28
13	South Branch Potomac River at Petersburg, West Virginia--TKN, NO_3, and PO_4 vs River Discharge	31
14	Computed Phosphate Profiles and Stream Survey Data for the Patuxent River Basin, 1967	[illegible]
15	Phosphorus Loadings--Above and Below Dam No. 5, Potomac River Basin, 1966.	37

LIST OF TABLES

Number	Description	Page
1	Wastewater Nutrient Loadings, Potomac River Basin, 1966	11
2	Estimated Nutrient Loadings from Land Runoff, Potomac River Basin, 1966	13
3	Estimated Total Potomac Basin Nutrient Loading, 1966	14
4	Comparison of Annual Average Nutrient Concentrations and Loadings, Major Subbasins of Upper Potomac River Basin, 1966	17
5	Predicted Average Monthly Nutrient Loadings, Potomac River Near Washington, D.C.	19

INTRODUCTION

As part of the Chesapeake Bay Susquehanna River Basins Project, the Chesapeake Technical Support Laboratory* (CTSL) of the Middle Atlantic Region of the Federal Water Pollution Control Administration (FWPCA) has undertaken an extensive water quality management study of the Potomac River Basin. Because of the increasing emphasis on eutrophication, a significant part of this study has been to determine the sources, temporal spatial distribution and transport mechanisms of the nutrients in the Potomac River Basin. Investigations were also initiated to determine the concentration of nutrients in the upper Potomac Estuary.

* Formerly the Chesapeake Field Station

DESCRIPTION OF THE POTOMAC RIVER BASIN

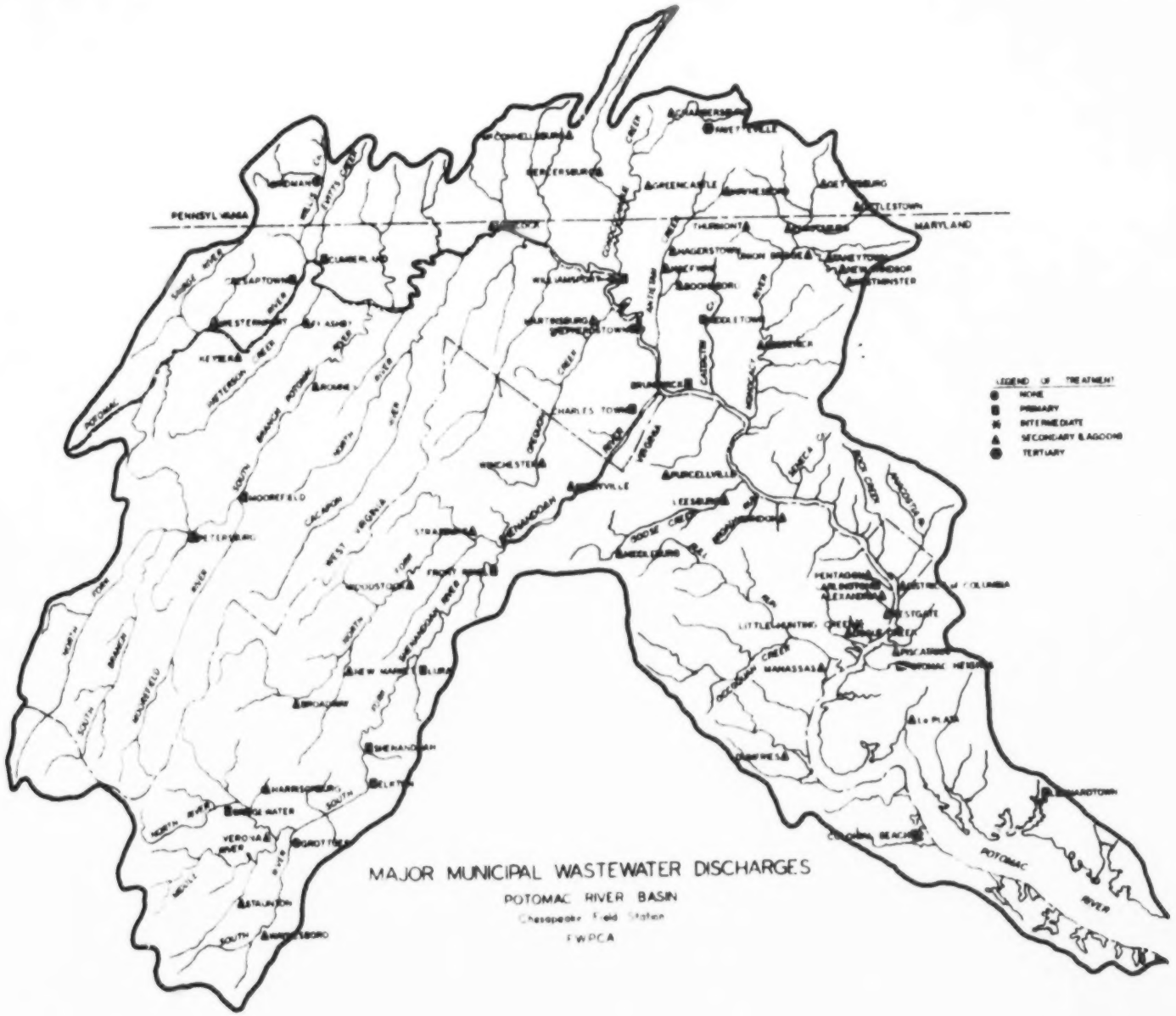
The Potomac River Basin has a drainage area of 14,670 square miles and encompasses parts of Pennsylvania, Maryland West Virginia. and Virginia and all of the District of Columbia. The major sub-basins including their drainage areas are:

Sub-basin	Drainage Area (square mile)
North Branch	1,328
South Branch	1,493
Cacapon River	683
Conococheague Creek	603
Opequon Creek	345
Antietam Creek	292
Shenandoah River	3,054
Monocacy River	970

Of the 3 million people living in the basin, about 2.5 million, or 83 percent, live in the Washington, D.C. metropolitan area. The industrial development is primarily concentrated in the North Branch of the Potomac near Luke and Cumberland, Maryland, and in the South Fork of the Shenandoah near Front Royal and Waynesboro, Virginia.

Land use in the sub-basins is either predominately forest, agriculture or urban. In the entire Potomac Basin it has been estimated that the land use is 5 percent urban, 55 percent forest and 40 percent agriculture including pasture lands.

A map of the basin showing major municipal wastewater discharges is presented in Figure 1. A detailed inventory of the industrial and municipal wastewater discharges within the basin is available [1].



MAJOR MUNICIPAL WASTEWATER DISCHARGES

POTOMAC RIVER BASIN

Chesapeake Field Station

FWPCA

FIGURE 1

SAMPLING PROGRAMS

A Potomac Estuary sampling network, established in 1965, was sampled on a short term intensive basis mainly for the low flow conditions of 1964, 1966 and 1967. During 1966, weekly sampling of this network was maintained for the six low flow months. A map of the estuary showing the major wastewater discharges is presented in Figure 2.

In order to develop the data necessary to determine the temporal and spatial distribution of the nutrients in the basin, a stream sampling network was developed consisting of 40 stations with a representative distribution throughout the basin (Figure 3). Samples were obtained weekly during the 1966 calendar year for most of the stations.

To aid in a further delineation of the various sources of nutrients, the stream sampling program was expanded to include weekly measurements of nutrients from 13 major wastewater discharges of the upper basin during the latter half of 1966. In 1966, major municipal and biodegradable industrial wastewater discharges with a flow greater than 0.5 mgd were sampled and an inventory prepared [1].

The stream network and wastewater samples were analyzed for total phosphorus, nitrite, nitrate, organic nitrogen and ammonia. The estuarine analysis program included the above plus orthophosphate, chlorophyll "a", and routine demand parameters. The sampling procedures and analytical methods are described in a detailed report by the CTSL [7].

FIGURE 2

PENNSYLVANIA

SOURCES OF NUTRIENTS (PHOSPHORUS AND NITROGEN)

1. Wastewater Effluents

As of December 1968, there were 382 known wastewater discharges in the Potomac River Basin [1]. The average phosphorus and nitrogen loadings from wastewater discharges in 1966 were 81,400 and 65,000 lbs/day respectively (Table 1). This reduces to 0.028 and 0.022 lb /capita/day of phosphorus* and nitrogen respectively.

The industrial contribution to the wastewater nutrient loading is about 10 percent of the phosphorus and 8 percent of the total nitrogen. The amount of NO_2 + NO_3 nitrogen in industrial and municipal wastewater effluents is insignificant.

2. Land Runoff

The effects of land use (forest, agricultural and urban) on the surface water nutrient concentrations are illustrated in Figures 4 and 5. These three areas receive a relatively small volume of wastewater.

In wooded areas, the concentrations of both phosphorus and inorganic nitrogen were the lowest for the three types of watersheds. For Catoctin Creek, which is mainly agricultural, the concentrations of both phosphorus and NO_2 + NO_3 nitrogen fluctuated considerably. The nigh NO_2 + NO_3 concentrations were observed during high stream flow conditions. (See Figure 12 for the 1966 stream flow hydrograph for the Potomac River at Great Falls.)

* In this paper all values of phosphorus are expressed as PO_4.

Table 1

WASTEWATER NUTRIENT LOADINGS

1966

Potomac River Basin

Area	Population Served	T. PO_4 as PO_4			TKN as N*		
		(lbs/day)	(% of total)	(lbs/cap/day)	(lbs/day)	(% of total)	(lbs/cap/day)
Upper Potomac (Above Estuary)	390,000	18,400**	22.6	.047	11,000	16.9	.028
Lower Potomac (Tidal Waters)	2,510,000	63,000	77.4	.025	54,000	83.1	.021
Total Basin	2,900,000	81,400	100.0	-	65,000	100.0	-
Average	-	-	-	0.028	-	-	.022

* The amount of $NO_2 + NO_3$ nitrogen in the wastewaters is insignificant.

** Includes about 2,800 lbs/day applied to land during summer months.

LAND USE COMPARISON

TOTAL PHOSPHORUS PO_4

POTOMAC RIVER BASIN

1966

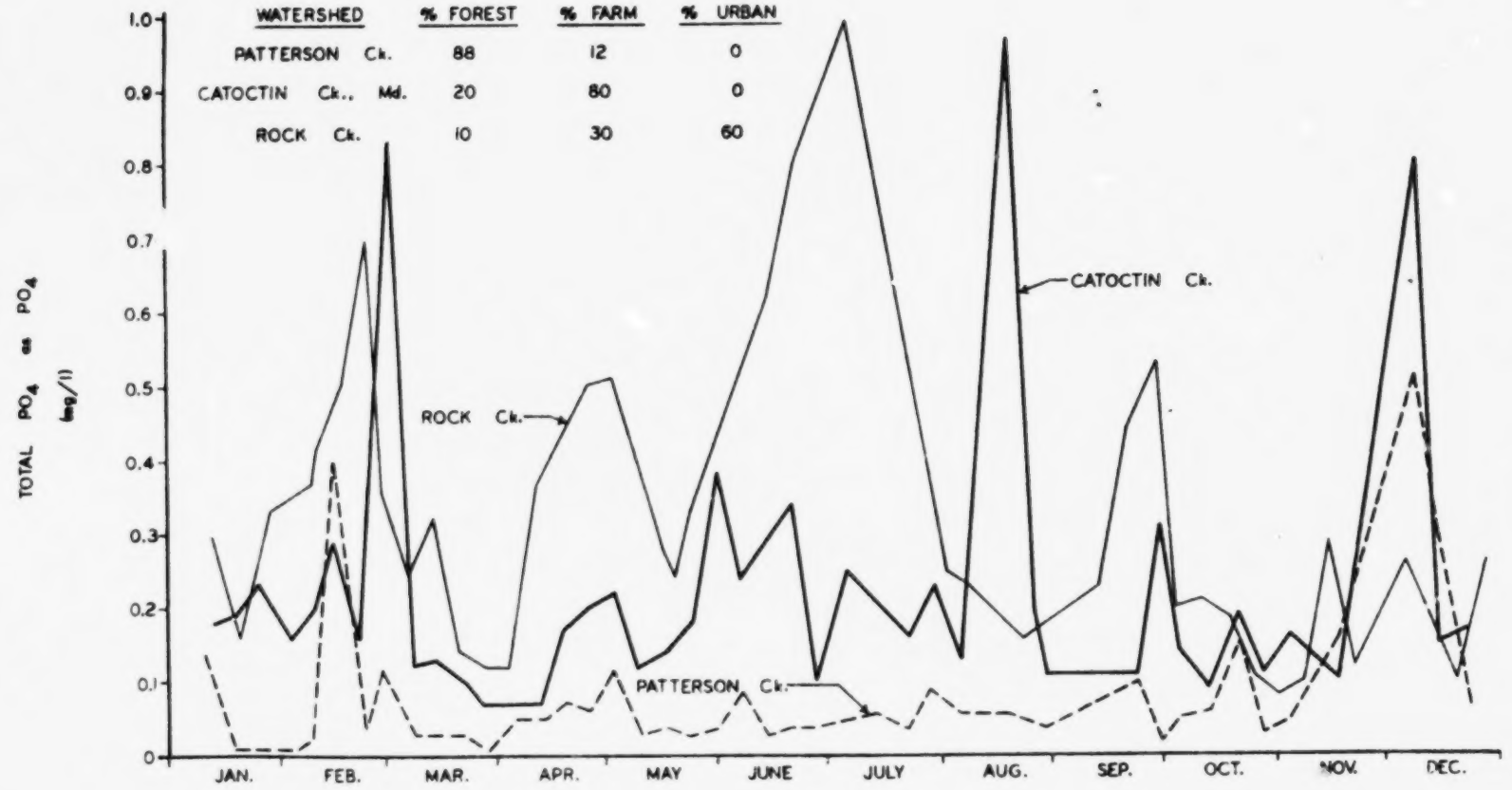


FIGURE 4

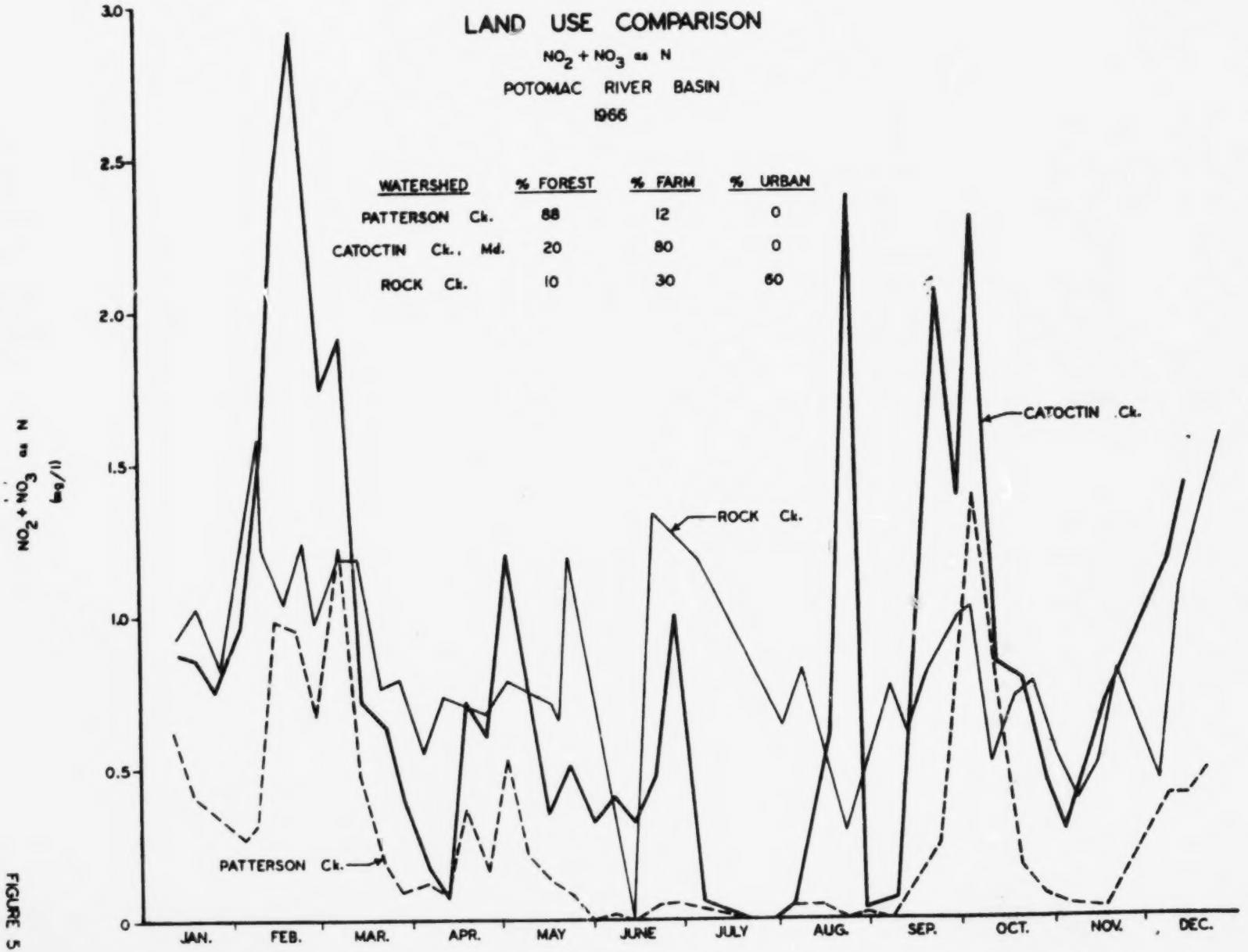

LAND USE COMPARISON
$NO_2 + NO_3$ as N
POTOMAC RIVER BASIN
1966
WATERSHED | % FOREST | % FARM | % URBAN
PATTERSON Ck. | 88 | 12 | 0
CATOCTIN Ck., Md. | 20 | 80 | 0
ROCK Ck. | 10 | 30 | 60
CATOCTIN Ck.
ROCK Ck.
PATTERSON Ck.
3.0
2.5
2.0
1.5
1.0
0.5
0
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
N as $S_{ON} + Z_{ON}$ (mg/l)

FIGURE 5

The average annual yield of phosphorus and nitrogen for the three watersheds are given below:

Watershed	Drainage Area (sq.mi.)	Total PO_4 as PO_4 (lbs/day/sq.mi.)	$NO_2 + NO_3$ as N (lbs/day/sq.mi.)	TKN as N (lbs/day/sq.mi.)
Patterson Creek	279	0.50	2.02	0.41
Catoctin Creek	109	1.25	5.30	0.65
Rock Creek	77	1.10	2.70	0.67

Watersheds having similar land uses and without large wastewater discharges have similar nutrient levels and seasonal variations.

Using the same land use delineation as the U.S. Corps of Engineers in the 1958 study [4], the nutrient loading from land runoff was determined and is shown in Table 2. It should be noted that the largest contribution of nutrients is from agricultural runoff even though over 50 percent of the basin is covered by forest.

3. Total Basin Nutrient Loadings

Utilizing data from sampling stations representative of various land usage and from the wastewater sampling program, a delineation of nutrient sources was obtained as presented in Table 3. For the two distinct drainage areas of this basin, upper Potomac above Great Falls and lower Potomac below Great Falls, the following summary of the sources was developed for 1966:

a. Of the estimated 94,130 lbs/day of total phosphorus as PO_4 which entered the surface waters of the entire basin, over 87 percent

Table 2

ESTIMATED NUTRIENT LOADINGS FROM LAND RUNOFF

Potomac River Basin

1966

Land Use	Area	T. PO_4 as PO_4		$NO_2 + NO_3$ as N		TKN as N	
	(sq.mi.)	(lbs/day/sq.mi.)	(lbs/day)	(lbs/day/sq.mi.)	(lbs/day)	(lbs/day/sq.mi.)	(lbs/day)
Agriculture*	5840	1.25	7880	5.30	30950	0.65	3800
Forest	8100	0.50	4050	2.02	16360	0.41	3320
Urban	730	1.10	800	2.70	1970	0.67	490
Total Basin	14670	0.86	12730	3.36	49280	0.52	7610

* Agricultural use includes both crop land and pastures.

Table 3

ESTIMATED TOTAL POTOMAC BASIN NUTRIENT LOADING

1966

Source	T. PO_4 as PO_4 (lbs/day)	% of total	NO_2 + NO_3 as N (lbs/day)	% of total	TKN as N (lbs/day)	% of total
Wastewater	81,400	87	*	0	65,000	89
Land Runoff	12,730	13	49,280	100	7,610	11
Total Basin	94,130	100	49,280	100	72,610	100

* The amount of NO_2 + NO_3 Nitrogen in the wastewater was insignificant.

on the average comes from wastewater discharges,

b. of the 94,130 lbs/day of PO_4, 62,000 lbs/day, or 66 percent of the basin total, entered the Potomac Estuary from wastewater discharges in the Washington, D.C. metropolitan area.

c. The total loading of nitrogen as N to the surface waters of the basin from all sources was estimated to be 122,190 lbs/day, of which 65,000 lbs/day, or 53 percent, were from wastewater discharges,

d. about 41 percent of the total nitrogen loading was from wastewater discharges in the upper Potomac Estuary, and

e. over 55 percent of the total nitrogen loading from wastewater discharges and other sources was in the TKN form of nitrogen.

TEMPORAL AND SPATIAL DISTRIBUTION OF NUTRIENTS IN THE UPPER POTOMAC BASIN

1. Phosphorus

As can be seen in the summary of the nutrient data for the major sub-basins in Table 4, the phosphorus concentrations were at least three times greater in the Monocacy River, Opequon Creek and Antietam Creek sub-basins than in the remaining five sub-basins. These three sub-basins are primarily agricultural and receive considerable quantities of municipal wastewater. These higher concentrations are also reflected in large yields of from 3.6 to 4.8 lbs/day/sq.mi., as also shown in Table 4.

Figure 6 shows that the phosphorus loadings (lbs/day) for the major upper sub-basins followed a seasonal pattern similar to that of river discharge. A comparison of the loadings in Figure 6 with the hydrograph presented in Figure 12 indicates that the large increase in September 1966 was a result of extremely large river discharges during the month.

2. Nitrite + Nitrate and Total Kjeldahl Nitrogen (TKN)*

The Conococheague, Antietam, Opequon and Monocacy sub-basins had average NO_2 + NO_3 nitrogen of 1.4 mg/l and greater. The Conococheague and Monocacy sub-basins had nitrite and nitrate yields of over 10 lbs/day/sq.mi., almost twofold larger than that of the remaining four sub-basins.

When expressed in pounds per day, as presented in Figure 7, it can be seen that most of the NO_2 + NO_3 nitrogen enters the surface waters during the high flow months. For the low flow months of June, July and

* In this report TKN includes both organic nitrogen and ammonia.

Table 4

[illegible]
AND LOADINGS
1[illegible]

[illegible] per [illegible]

Site no. (fig. 1)	Drainage Area (sq. mi.)	[illegible] (mg/l)	[illegible] (lbs/day)	[illegible] (lbs/day/sq. mi.)	[illegible] (mg/l)	[illegible] (lbs/day)	[illegible] (lbs/day/sq. mi.)	[illegible] (mg/l)
[illegible] (Point Pleasant, W. Va.)	1[illegible]	.[illegible]	[illegible]	1.[illegible]	.[illegible]	[illegible]	[illegible]	.[illegible]
[illegible] (Burnsville, W. Va.)	[illegible]	.[illegible]	[illegible]	[illegible]	.[illegible]	[illegible]	[illegible]	-
[illegible] ([illegible], W. Va.)	[illegible]	.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.[illegible]
[illegible] ([illegible], W. Va.)	2[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	.[illegible]
[illegible] (Morgantown, W. Va.)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.[illegible]
[illegible] (Pinomer, W. Va.)	3012	.[illegible]	[illegible]	[illegible]	.[illegible]	[illegible]	[illegible]	.[illegible]
[illegible] ([illegible], W. Va.)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.[illegible]
[illegible] ([illegible], W. Va.)	[illegible]	.[illegible]	[illegible]	[illegible]	.[illegible]	[illegible]	[illegible]	.[illegible]

* [illegible]

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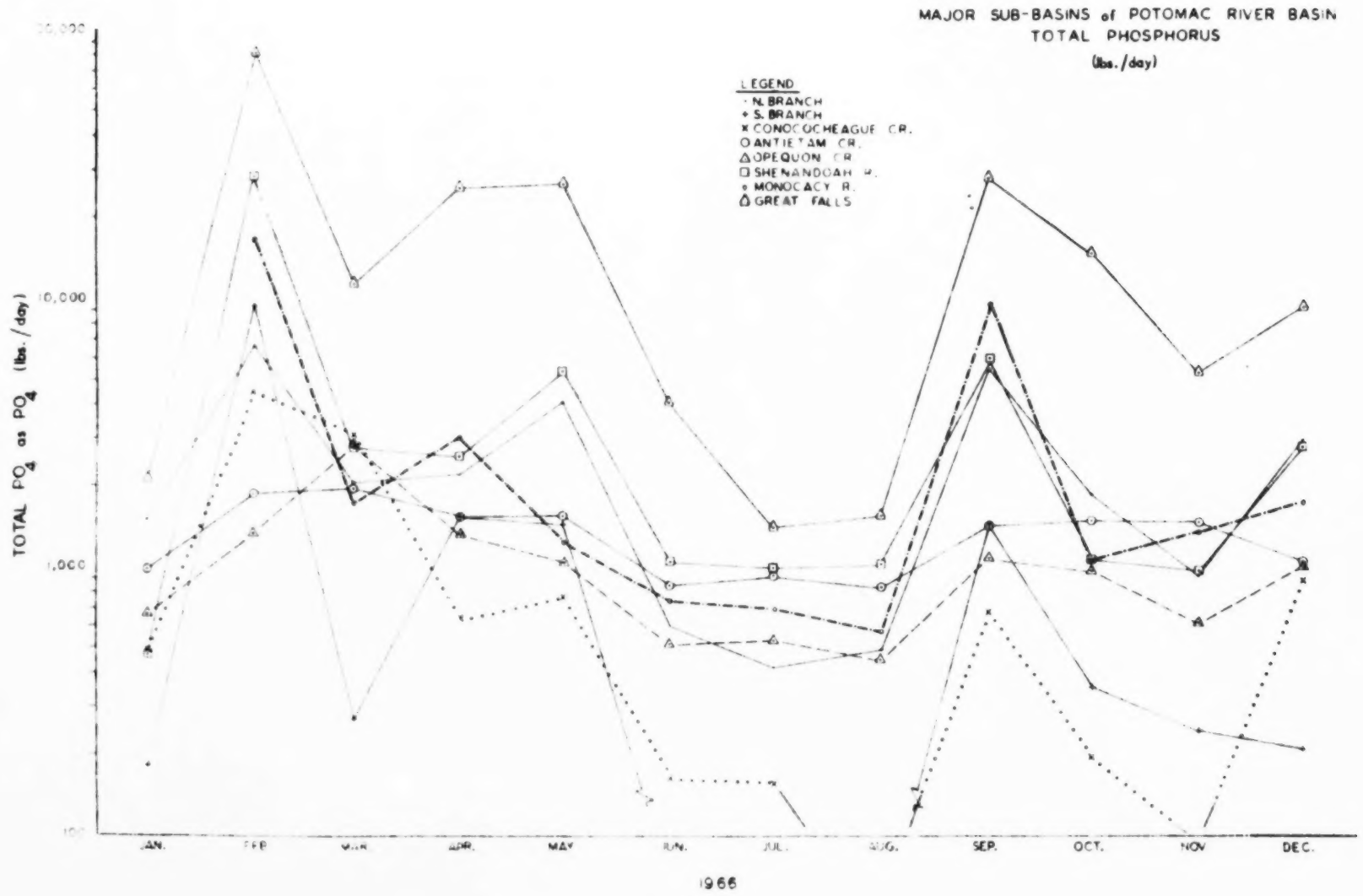
MAJOR SUB-BASINS of POTOMAC RIVER BASIN
TOTAL PHOSPHORUS
(lbs./day)
LEGEND
N. BRANCH
S. BRANCH
CONOCOCHEAGUE CR.
ANTIETAM CR.
OPEQUON CR.
SHENANDOAH R.
MONOCACY R.
GREAT FALLS
TOTAL PO4 as PO4 (lbs./day)
10,000
1,000
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV
DEC.
1966

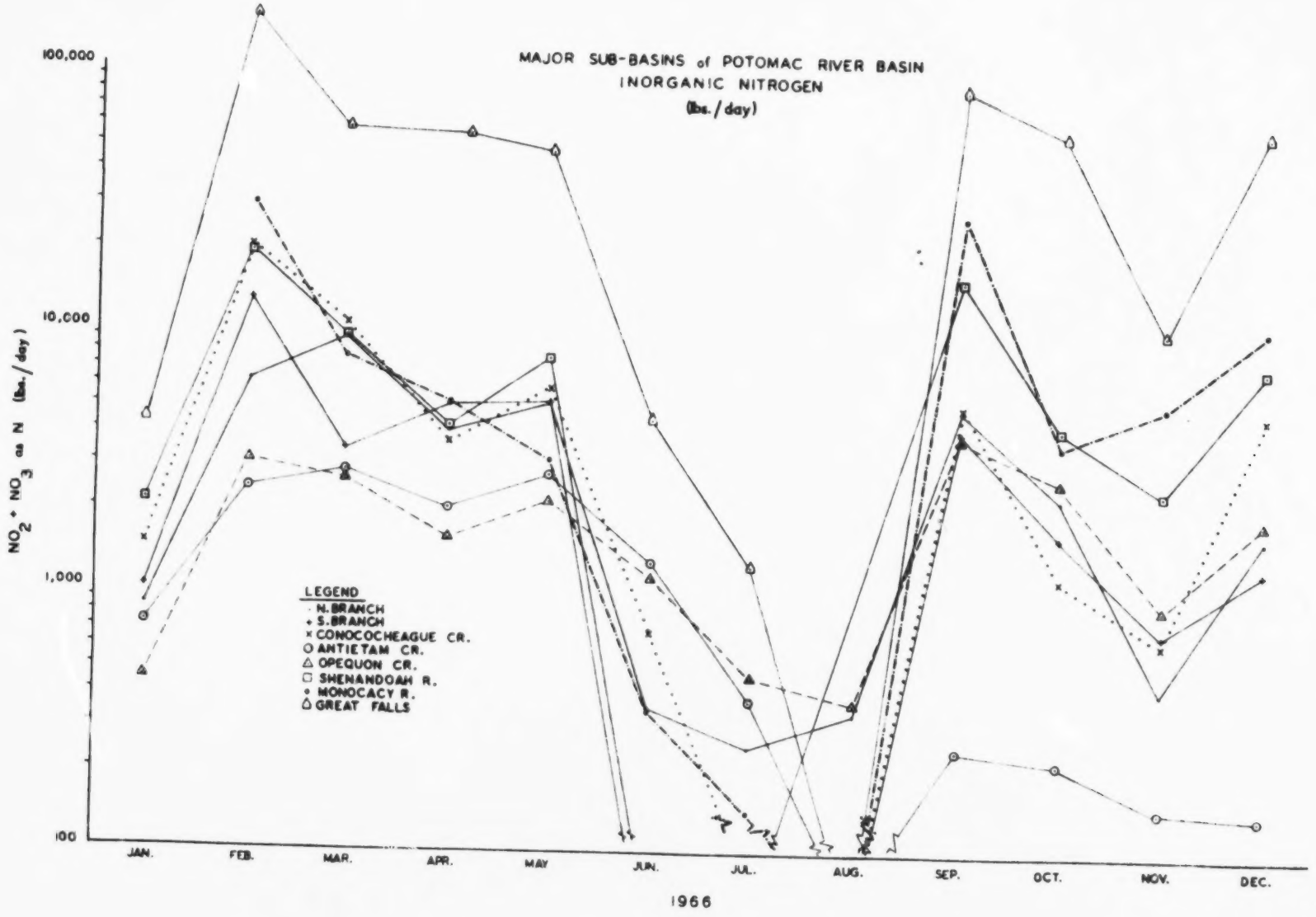
MAJOR SUB-BASINS of POTOMAC RIVER BASIN
INORGANIC NITROGEN
(lbs. / day)
100,000
10,000
1,000
100
$NO_2 + NO_3$ as N (lbs./day)
LEGEND
N. BRANCH
S. BRANCH
CONOCOCHEAGUE CR.
ANTIETAM CR.
OPEQUON CR.
SHENANDOAH R.
MONOCACY R.
GREAT FALLS
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1966

FIGURE 7

August of 1966, the NO_2 + NO_3 nitrogen loadings were less than 400 lbs/day for the major sub-basins.

Since the TKN determination was initiated in the midsummer of 1966, annual loadings were not calculated for this parameter. The average TKN concentration ranged from 0.017 to 0.784 mg/l.

NUTRIENT AND CHLOROPHYLL CONCENTRATIONS IN THE ESTUARY

As presented in the isopleth* in Figure 8, the Total Kjeldahl Nitrogen concentrations were the highest in the reach from the 14th Street Bridge (River Mile 6.0) to Indian Head (River Mile 29.0). In the upper estuary near Woodrow Wilson Bridge (River Mile 11.8), concentrations of 3.0 mg/l and greater were observed in July and August. The four major wastewater discharges of the Washington, D.C., metropolitan area are within the tidal excursion of the Woodrow Wilson Bridge.

The end product of the oxidation of TKN is nitrite + nitrate nitrogen.** As shown in Figure 9, the high concentrations of $NO_2 + NO_3$ (above 1.5 mg/l) were observed farther downstream and lagged in time when compared to the level of TKN in the estuary. The TKN and $NO_2 + NO_3$ concentrations of the water entering the estuary during the months of July through October were about 0.7 and 0.1 mg/l, respectively.

* An isopleth, which exhibits a complete graphical presentation of water quality with respect to location and time along the estuary, is useful for depicting variations of a parameter at a given location for a specific time or for a given time period along the estuary. The isopleths were constructed by plotting all data for a given station along the estuary for the six-month period. A smooth curve was fitted to these data as representative of "average" conditions during the entire survey period.

** Nitrite is a temporary but essential form of oxidized nitrogen and is considered with nitrate ($NO_3 + NO_2$).

TKN as N ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY — OCTOBER 1968

CHESAPEAKE TECHNICAL SUPPORT LABORATORY

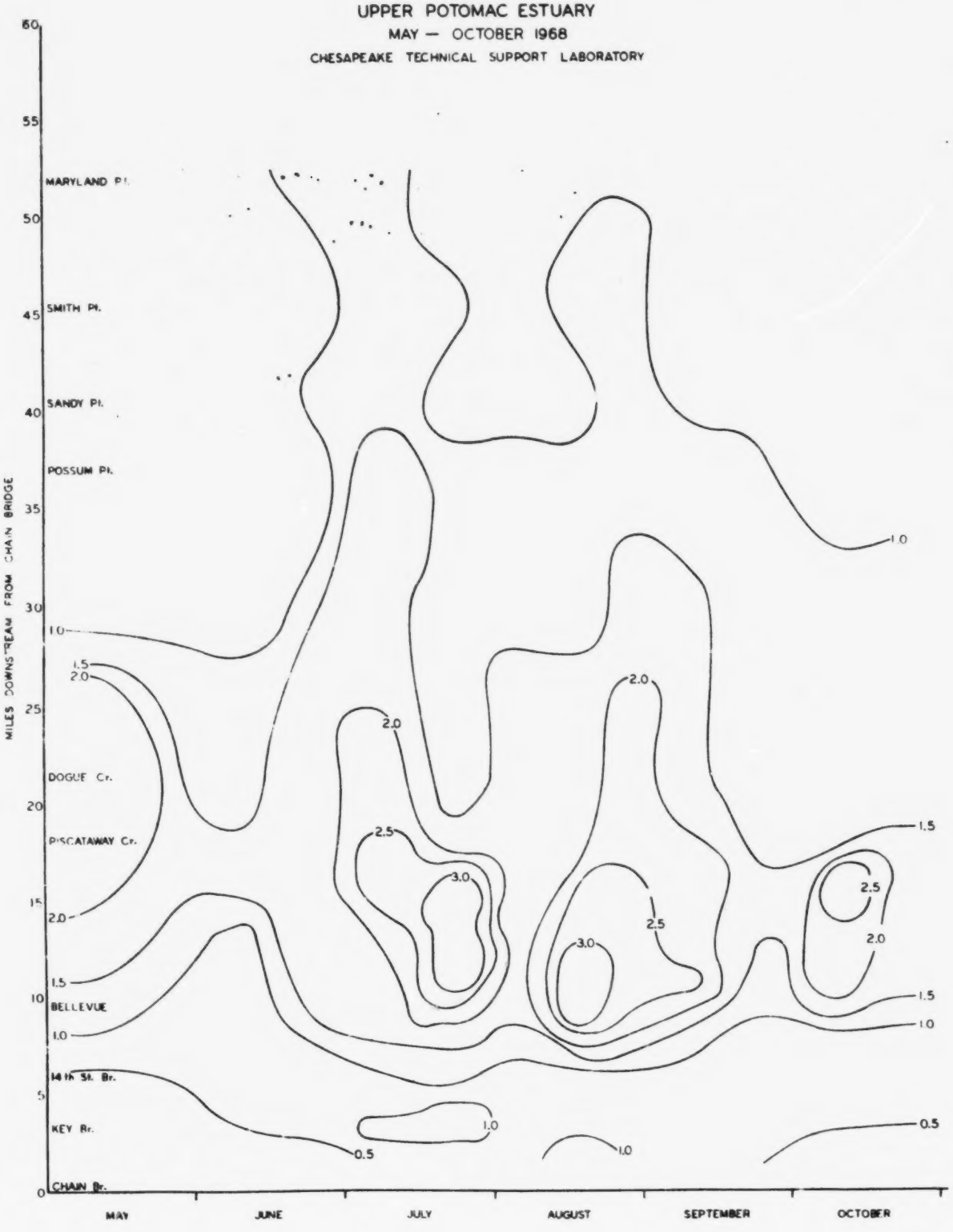

FIGURE 8

$NO_2 + NO_3$ as N ISOPLETH
(mg/l)
UPPER POTOMAC ESTUARY
MAY — OCTOBER 1968
CHESAPEAKE TECHNICAL SUPPORT LABORATORY

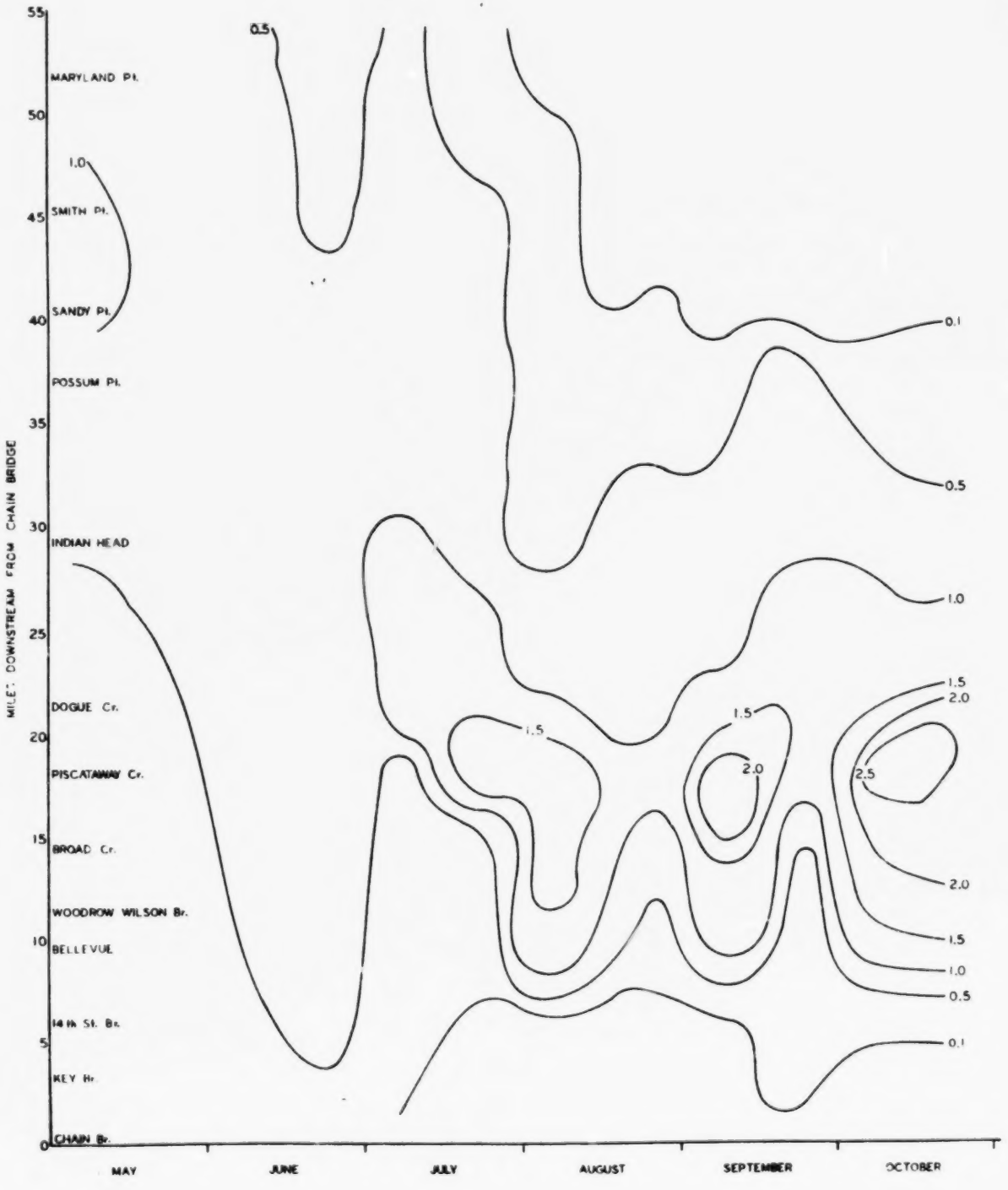

FIGURE 9

The phosphorus concentrations were similar to TKN levels during the period from May through October (Figure 10). During the months of August, September and October, the concentration of phosphorus was 2.0 mg/l and greater in the vicinity of Woodrow Wilson Bridge with fresh water inflow entering the estuary varying from 0.16 to 0.423 mg/l of phosphorus.

Using chlorophyll "a" as a measure of algal standing crop, the isopleth presented in Figure 11 indicates that there was a widespread bloom* in the Potomac Estuary during the summer months of 1968. For the month of August, chlorophyll levels of 150 µg/l and greater were observed from Bellevue (River Mile 9.7) to Hallowing Point (River Mile 20.0).

During the months of May and June, the predominant algal species in the upper estuary was Chlamydomonas sp., a green flagellate. During the months of July through September the predominant species was Anacystis cyanea, a coccoid blue-green algae. During the month of November, the predominant phytoplankton was Chlorella, a coccoid green algae.

The CTSL [3]is currently assessing water quality conditions and factors affecting water quality in the Potomac Estuary.

* Bloom conditions are observed when chlorophyll concentrations are 50 µg/l and greater.

TOTAL P as PO_4 ISOPLETH

(mg/l)

UPPER POTOMAC ESTUARY

MAY — OCTOBER 1968

CHESAPEAKE TECHNICAL SUPPORT LABORATORY

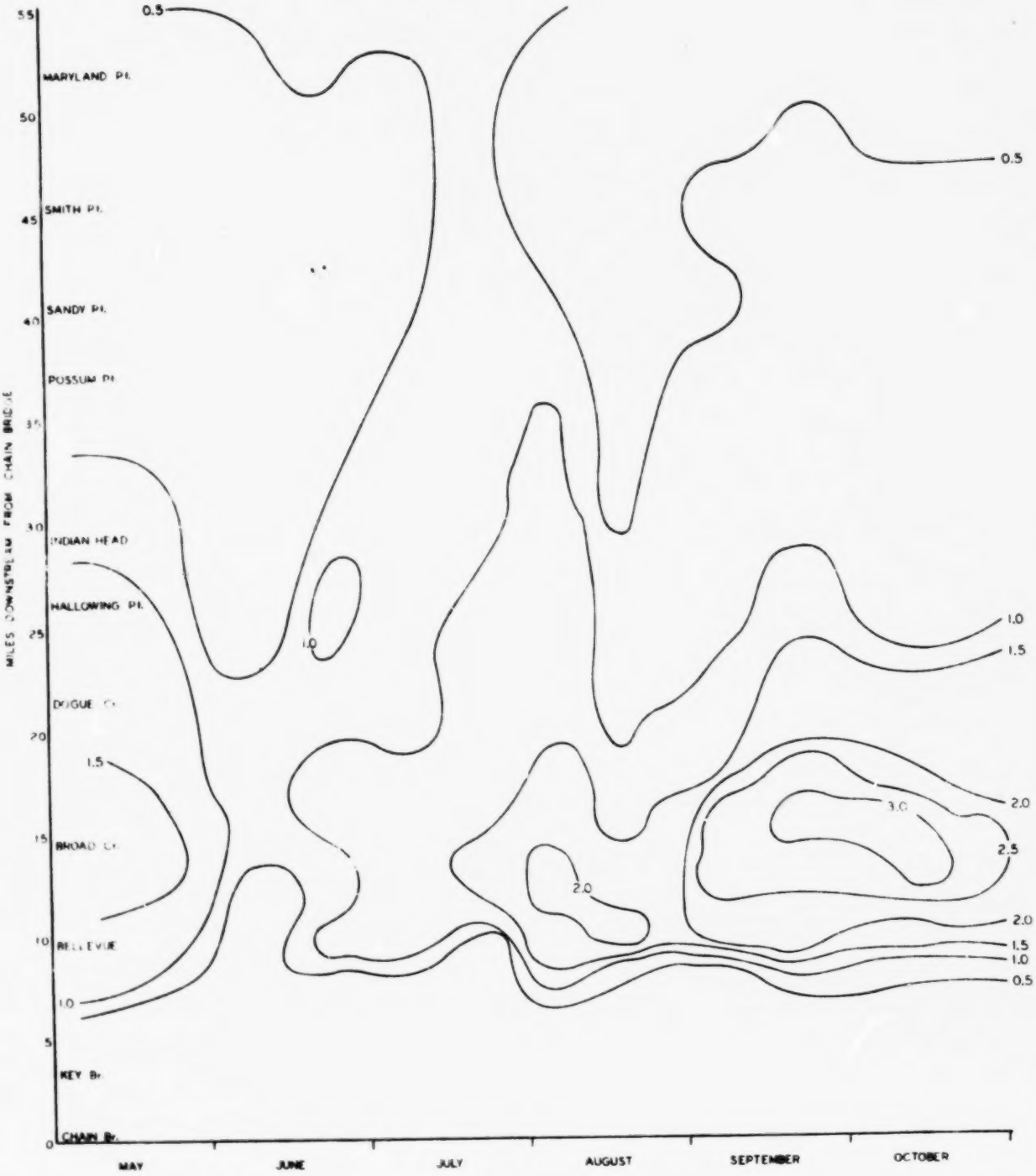

FIGURE 10

CHLOROPHYLL ISOPLETH

(µg/l)

UPPER POTOMAC ESTUARY

MAY — OCTOBER 1968

CHESAPEAKE TECHNICAL SUPPORT LABORATORY

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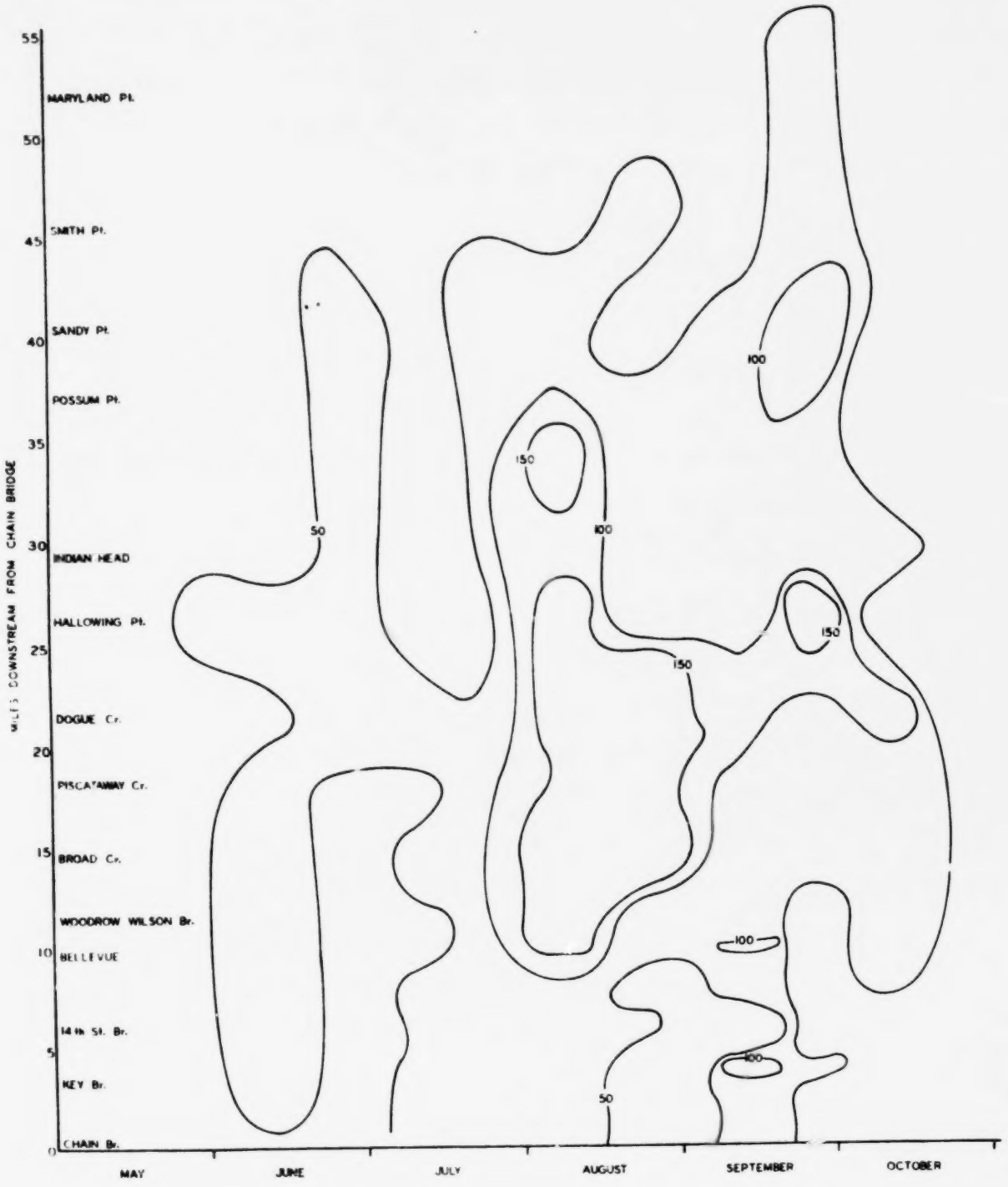


FIGURE 11

TEMPORAL DISTRIBUTION OF NUTRIENTS ENTERING THE POTOMAC ESTUARY

1. Temporal Variations

A very important aspect of the nutrient control problem is the annual variation in nutrient contribution by the various sources. The amount of phosphorus and nitrogen variation for the mainstem station of the Potomac at Great Falls can be readily seen in Figure 12. During the summer months, less than 1000 lbs/day of phosphorus entered the estuary even though more than 18,400 lbs/day are discharged to the surface waters in the upper basin from wastewater treatment plants.

Regression analyses were made on the data for the station at Great Falls obtained during the period 1961 - 1967. Predictive equations based on river discharge were developed, as given below:

Parameter	Equation (Q=river discharge in cfs)	Correlation Coefficient
NO_2* (lbs/day)	$= 0.0337Q^{1.058}$	0.865
NO_3* (lbs/day)	$= 0.0362Q^{1.475}$	0.903
$NO_2 + NO_3$** (lbs/day)	$= 0.0361Q^{1.546}$	0.924
TKN (lbs/day)	$= 0.0965Q^{0.892}$	0.927
T. PO_4 (lbs/day)	$= 0.2651Q^{1.179}$	0.964

Table 5 presents the predicted average monthly nutrient loadings based on the average monthly flows for the Potomac River at Great Falls,

* Based on data from the U.S. Army Corps of Engineers, Delecarlia Water Treatment Plant for 1961 - 1967.
** Based on CFS data for 1966.

NUTRIENT LOADINGS and RIVER DISCHARGES

POTOMAC RIVER at GREAT FALLS, Md.

1968

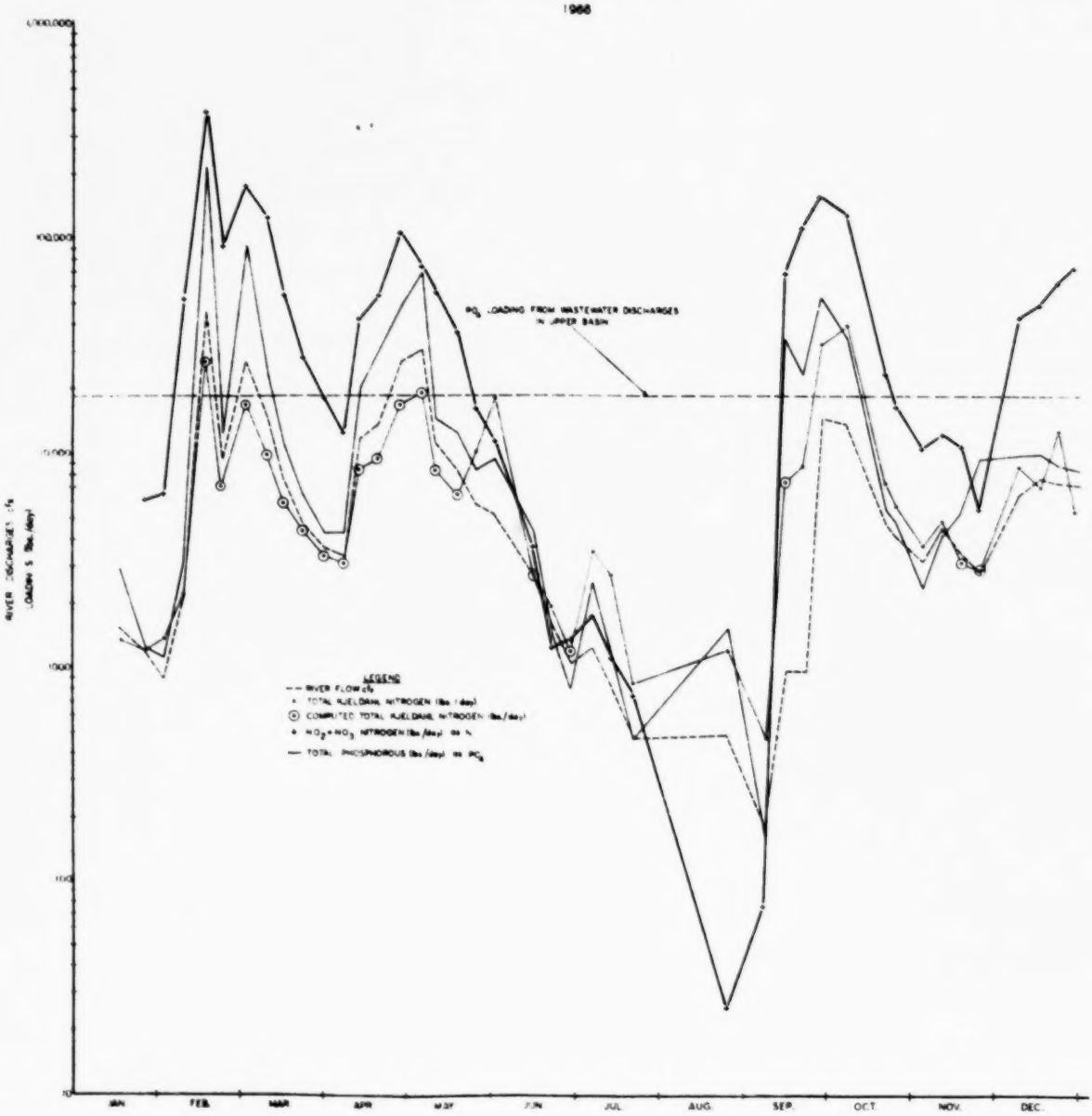


FIGURE 12

Table 6

ADJUSTED AVERAGE MONTHLY WATER LOADING

Potomac River

Near Washington, D.C.

Month	Flow* (mgd)	C_5 as O_2 lbs /day	N as (lbs /day)	NO_2 + O_3 as N (lbs /day)
[illegible]	[illegible]	20,130	4,820	36,000
[illegible]	[illegible]	[illegible],171	11,610	121,000
[illegible]	21,[illegible]	[illegible],770	14,140	[illegible],[illegible]0
[illegible]l	20,000	[illegible],[illegible]0	12,[illegible]0	[illegible],000
[illegible]	[illegible],[illegible]0	2[illegible],000	10,[illegible]	[illegible], 00
[illegible]	[illegible],[illegible]8	1[illegible],420	[illegible],780	[illegible],[illegible]70
[illegible]	,456	[illegible],000	[illegible],610	21,[illegible]00
.	.112	10,180	[illegible],060	2[illegible],[illegible]60
.	[illegible],747	[illegible],[illegible]60	[illegible],190	[illegible],[illegible]00
.	[illegible],210	[illegible],[illegible]80	[illegible],200	2[illegible],060
.	[illegible], [illegible]	11,100	[illegible],3[illegible]0	28,[illegible]00
.	[illegible],036	17,250	[illegible],5[illegible]0	[illegible]4,200
[illegible]ean	11,12[illegible]	21,180	[illegible],1[illegible]	[illegible]1,[illegible]10

[illegible] monthly flows adjusted for diversions.

Maryland, from the upper basin. The largest variation in the loadings is in nitrite-nitrate nitrogen, which varied from 17,400 to 174,800 lbs/day.

These variations are more pronounced if daily values are considered. For example, in August of 1966, with a river discharge of about 500 cfs, less than 1000 lbs/day of total phosphorus as PO_4 and $NO_2 + NO_3$ as N entered the upper estuary from the upper Potomac River Basin, while on February 14, 1966, with a flow greater than 40,000 cfs, about 217,000 and 354,000 lbs/day of PO_4 and $NO_2 + NO_3$ as N, respectively, entered the estuary.

The high variation in $NO_2 + NO_3$ nitrogen can be attributed to high mobility of NO_3 ion as reported by Wadleigh [5] and Bailey [6]. As can be seen in Figure 13 for the South Branch station at Petersburg, the concentration of nitrates is directly related to river discharge while concentrations of TKN and PO_4 are indirectly related. Similar observations were made for the 35 non-tidal sampling stations.

2. Mass Balances

The phosphorus loading at any given sampling point in the basin is dependent upon many variables such as flow, soil condition and land usage. On an annual basis, the amount of phosphorus can be expressed mathematically as follows:

$$P_t = P_w + P_l + P_o \pm P_s$$

where:

P_t = phosphorus observed at Point t

P_w = phosphorus in wastewater discharge above Point t

SOUTH BRANCH POTOMAC RIVER

AT

PETERSBURG, WEST VIRGINIA

TKN, $NO_2 + NO_3$ and PO_4 Vs. RIVER DISCHARGE

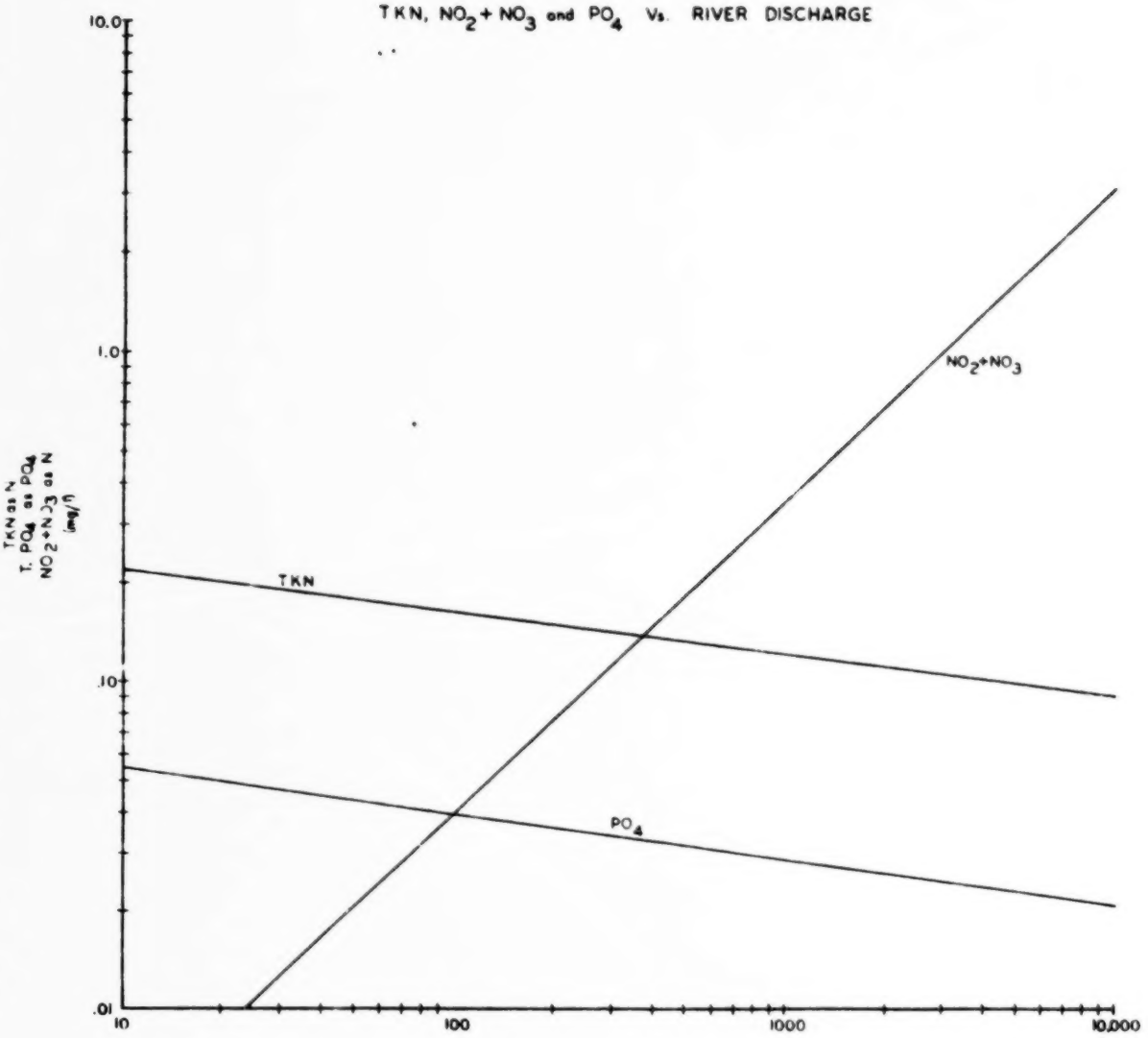


FIGURE 13

P_l = phosphorus coming from land above Point t

P_o = phosphorus from other sources above Point t

P_s = phosphorus lost or gained from storage in the stream bed

Utilizing the data from 1966 and rearranging the above formulation for the area of the Potomac River above Great Falls, Maryland:

$$P_s = P_t - P_w - P_l - P_o$$

and substituting the 1966 annual average phosphorus contributions

$$P_s = 17,000 - 18,400 - 9,600 - 0$$

or:

P_s = -11,000 lbs/day (loss to storage)

The negative sign on the phosphorus loadings storage value indicates that about 38 percent of the phosphorus which entered the waters of the upper Potomac River in 1966 was retained in the stream channel bound by the sediments, aquatic plants, etc. Although no core data are available for the upper Potomac to support this loss, data from the estuary indicate there is a more than fivefold increase in phosphorus in the sediment near wastewater discharges.

The predicted phosphorus loading for an average stream flow year on an average monthly flow basis (21,000 lbs/day) (Table 5) at Great Falls is less than the total loading (28,000 lbs/day) from wastewater discharge (18,400) and land runoff (9,600). This apparent loss of phosphorus to sediments may be temporary in that during flood conditions a considerable tonnage of sediment is transported into the estuary in a period of days [7].

The measured phosphorus loading to the estuary in 1966 was 62,000 lbs/day from wastewater discharges in the Washington, D.C. area and 17,000 lbs/day from all sources in the upper basin. On a measured annual percentage basis, about 90 percent of the phosphorus was from the wastewater discharges. However, during summer conditions, over 99 percent was from the wastewater discharges.

The wide variation in the loadings vividly demonstrates the need to sample on an annual basis before a delineation of nutrient sources can be attempted. Moreover, as can be seen in Figure 12, sampling during summer low flow conditions only can yield very misleading conclusions as to the relative contribution of nutrients.

NUTRIENT TRANSPORT

1. Transport Model for Phosphorus

To gain a further insight into the temporal distribution of nutrients, an analysis of the data from various intensive surveys in the Potomac and Patuxent* River Basins were made by the Chesapeake Technical Support Laboratory [7]. The transport of phosphorus for steady state flow conditions has been expressed mathematically as given below.

$$L_t = L_o e^{-kt}$$

where:

L_t = phosphorus at time t (mg/l or lbs/day)

L_o = initial concentration of phosphorus (mg/l or lbs/day)

k = transport coefficient

t = time elapsed in days

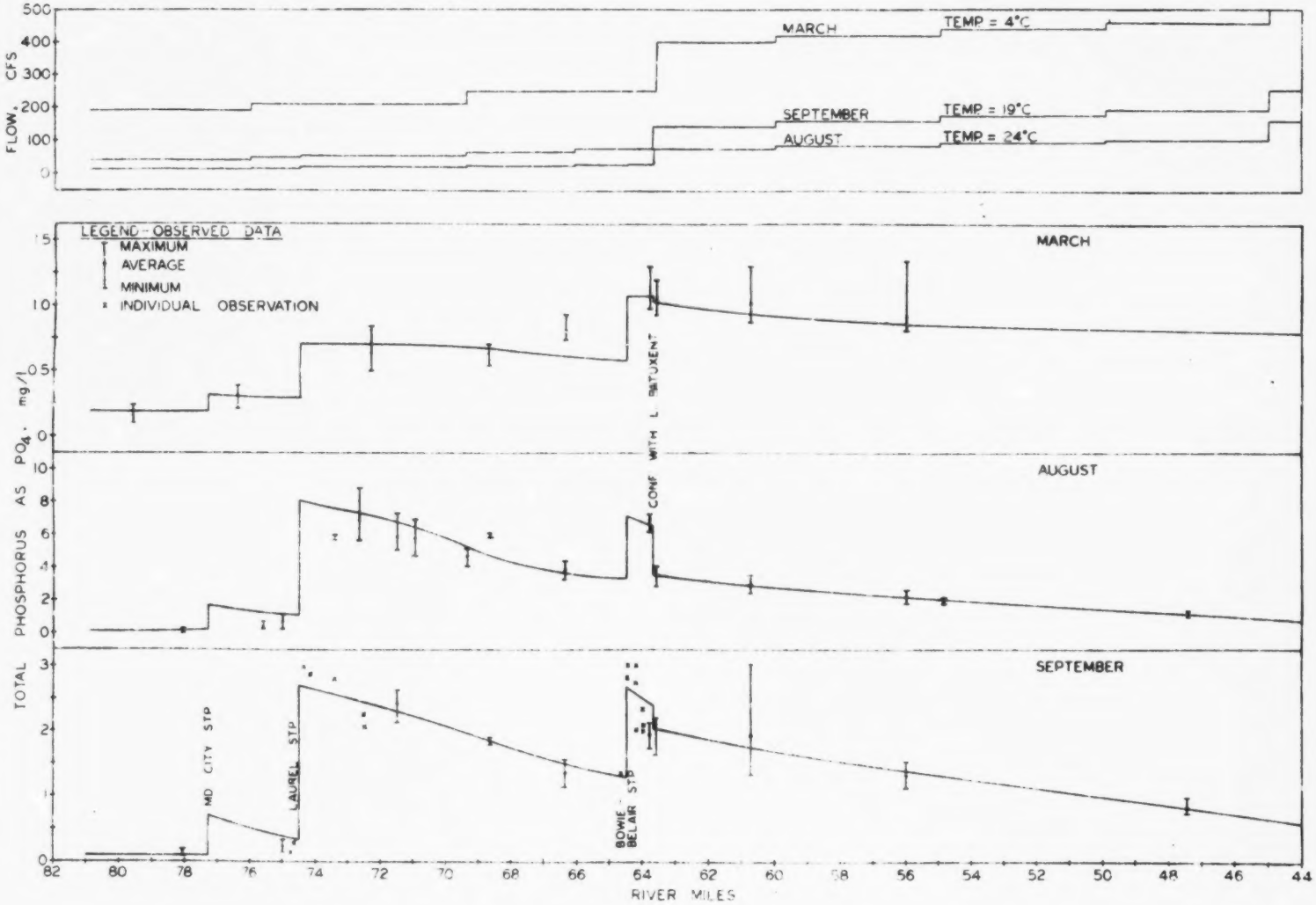
Figure 14 presents computed and observed data for the Patuxent River Basin with the values of k varying from 0.1 to 0.3 (base 10). The close agreement between the observed and the computed profiles indicates the transport of phosphorus can be approximated by the above model.

2. Effects of Small Impoundments on Nutrient Transport

To determine net poundage of nutrients trapped or released by the low level impoundments (less than 20 feet deep) in the Potomac Basin, a detailed analysis was made of the data from the stations above and

* The Patuxent River Basin, which is adjacent to and about one-tenth the size of the Potomac River Basin, lies wholly within the State of Maryland.

COMPUTED PHOSPHATE PROFILES & STREAM SURVEY DATA FOR THE PATUXENT RIVER BASIN, 1967



below Dam No. 5*. Figure 15 presents total phosphorus loadings for the two stations. Using predictive equations developed from regression analyses, the average loadings were calculated for the year 1966 as tabulated below:

Parameter	Above the Impoundment (Hancock) (lbs/day)	Below the Impoundment (Hagerstown) (lbs/day)	Increase or [Decrease] (%)
PO_4 as PO_4	2770	2240	[24.5]
$NO_2 + NO_3$ as N	5125	5170	0.9
TKN as N	5835	4365	[25.3]

As can be seen in the above tabulation, Dam No.5 appears to have removed about 25 percent of the TKN and phosphorus while having relatively no effect on the $NO_2 + NO_3$ nitrogen. The stability of this apparent removal is unknown at present. Moreover, extremely high runoff periods during which these small impoundments are "flushed out" exert an unknown effect on nutrient removal. Nevertheless, it appears that small impoundments can act as selective nutrient traps but the total effect of these traps on the entire nutrient transport problem is unknown at the present time.

* Dam No. 5, which is between Stations 9 and 10 as shown in Figure 3, is a run-of-the-river hydroelectric power dam with a height of 17 feet and a length of 7 miles.

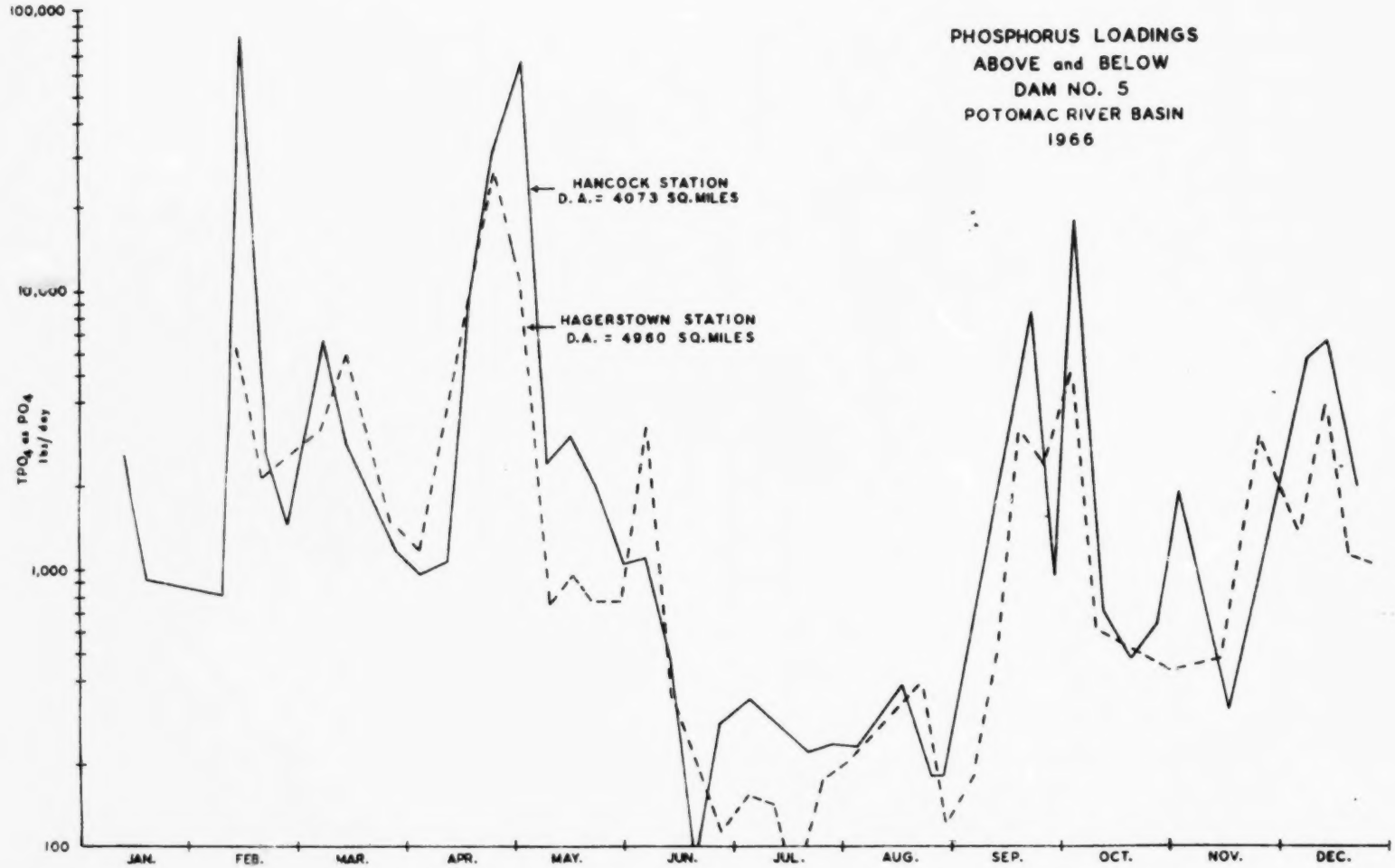

PHOSPHORUS LOADINGS
ABOVE and BELOW
DAM NO. 5
POTOMAC RIVER BASIN
1966
HANCOCK STATION
D. A. = 4073 SQ. MILES
HAGERSTOWN STATION
D.A. = 4960 SQ. MILES
TPO4 as PO4
lbs/day
100,000
10,000
1,000
100
JAN.
FEB.
MAR.
APR.
MAY.
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

FIGURE 15

SUMMARY AND CONCLUSIONS

Results of the initial phase of the nutrient investigations in the Potomac River system, which are being continued by the CTSL, are summarized below:

1. About 94,130 lbs/day of total phosphorus as PO_4 entered the surface waters of the Potomac in 1966, of which 67 percent resulted from wastewater discharges.

2. The average 1966 loading of total nitrogen as N from all sources to the surface waters of the basin was about 122,190 lbs/day, of which 65,000 lbs/day, or 53 percent, were from wastewater discharges.

3. Seasonal variations in inorganic nitrogen loadings are much more pronounced when compared to phosphorus. This is mainly attributed to a direct relationship between stream flow and inorganic nitrogen concentration for the stations in the non-tidal portion of the basin while phosphorus generally has an inverse relationship.

4. On a per capita basis, the average contributions of phosphorus as PO_4 and TKN as N in wastewater discharges are about 0.028 and 0.022 lb/day/capita, respectively.

5. Nutrient loadings from land runoff are greatly affected by land use. For the Potomac Basin in 1966, the average contributions of nutrients from land runoff were 0.86, 3.36 and 0.52 lbs/day/sq.mi. of phosphorus as PO_4, NO_2 + NO_3 as N, and TKN, respectively.

6. Transport studies demonstrated that under steady state stream flow conditions, considerable phosphorus can be retained in the stream channel, apparently bound by sediments, aquatic plants, etc.

7. Mass balances on an annual basis for 1966 indicated that about 38 percent of the phosphorus, which entered the surface water in the upper basin, was retained in the stream channel. The stability of the entrainment is unknown.

8. During low flow months, the high concentrations of TKN, nitrates and phosphates in the upper Potomac Estuary are attributed mainly to the wastewater discharges in the Washington, D.C. metropolitan area.

9. Widespread algal blooms with chlorophyll "a" concentrations of 50 µg/l and greater were observed for about 50 miles of the upper estuary from June through October 1968.

10. The wide variation in stream loading vividly demonstrates the need to sample on an annual basis before a delineation of nutrient sources can be attempted.

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